IPG2023-0001

DEVELOPMENT OF A PROTECTION SYSTEM WITH PRECAST CONCRETE BLOCKS

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ABSTRACT

The increase in demand for Alluvial Mitigation Works (AMW) for the development of Vaca Muerta, the main unconventional oil field of YPF and Argentina, prompted the search and analysis of different materials for the construction of said works.

Precast concrete blocks emerge as an innovative protection system that meets the needs of numerous YPF projects, resolving cases of low or moderate hydraulic stress, minimizing costs, labour, and execution times.

Covering with concrete blocks is a modern technique, applied in various countries, for erosion control and protection of hydrocarbon facilities. In the Neuquén region there is no commercial product of this type. The technical and economic evaluation of this solution justified the development of precast blocks for mass production in industrial plant, which required the construction of custom metal molds.

For the design of the blocks, called HR (rough hexagonal), other commercial models not available in the country were observed. An open block configuration was adopted, with less weight and greater roughness or resistance to flow, which decreases the speed in steep channels, typical of land in large sectors of the region.

For the application of the system in projects, it was necessary to have a verification methodology for current stability (Pilarczyk) that considers the characteristics of the system and material (loose blocks) and the hydraulic operating conditions (velocity, depth and roughness).

Subject to manufacturing by means of an automatic vibro compaction and steam curing machine, which significantly reduces the cost of the material, four models of HR blocks with thicknesses from 60 to 120mm and widths from 200 to 250mm were defined.

HR precast blocks are an experimental revetment applied in numerous works underway by YPF in non-conventional mining areas. According to the first experiences, the system presents clear economic, constructive and operational advantages compared to other traditional materials used in the region.

Continuous monitoring of the construction process and its operational phase allows us to evaluate possible adjustments or improvements to the system, as well as to identify limitations under certain adverse conditions. Construction experience facilitates greater knowledge of construction details to be considered in engineering

In parallel to the construction, it is intended to carry out a study in 3D hydraulic modeling (CFD) in order to determine the stability conditions and the effective roughness in certain scenarios. The numerical simulation will allow a more precise knowledge of the operation of the system, supporting the experimental phase in full development. In the scope of the study, the current geometries (HR) will be analyzed as well as new models under study.

1. INTRODUCTION

The development of Vaca Muerta, the main unconventional oil and gas field in Argentina, in charge of YPF Unconventional (YPF NOC), presents great challenges both underground and on the surface, where the facilities must overcome the obstacles of the terrain and their natural drainage, requiring in many cases the construction of important Alluvial Mitigation Works (AMW).

A water risk study evaluates the interaction between facilities and watercourses, identifying possible damages or affectations caused by water flows coming from the natural drainage of the land under heavy rains.

Water risk can be defined as the product of the probability of a dangerous event occurring and the adverse consequences of that event on people, the environment or property. The main components are:

- Danger: is the danger potential inherent in natural phenomena that can be exacerbated by human actions (torrential floods).
- Exposure: refers to the location of assets that may be affected by a catastrophic event (location, plant, pipelines, etc.).

- Vulnerability: is the intrinsic predisposition of an element to suffer damage from a phenomenon of a certain intensity (damage resistance).
- Uncertainty: refers to the limitations of knowledge of natural phenomena and extraordinary events (frequency of heavy rains).

Alluvial Mitigation Works (AMW) are hydraulic structures that are designed and built with the aim of minimizing the risks of damage that runoff could cause on a facility, avoiding its flooding and/or soil erosion after heavy rains on the ground. that drains towards them.

The AMW are designed considering the following main objectives:

- ✓ Drainage control
- ✓ Flood containment
- ✓ Erosion control
- ✓ Protection of facilities

Drainage control works are linked to the possibility of implementing berms, guard ditches, diversion channels or other necessary elements for the collection and conduction of flows that affect the facilities under project and/or existing facilities.

Flood containment refers to containment structures for water levels or natural runoff that affect facilities under project and/or existing facilities.

In erosion control works, the objective is the protection of land or structures vulnerable to erosion, avoiding damage to the structure, loss of soil, undermining of the support ground, loss of covers or any other process that modifies the integral safety of a projected or existing facility.

AMW are hydraulic structures designed as a protection for the facilities, modifying the conditions of flow and/or soil erosion. These works are projected contemplating the following structural functions:

- ✓ Stability and resistance
- ✓ Durability (useful life of the installation)
- ✓ Capture and conduction of flows
- ✓ Containment of water levels
- ✓ Erosion control

2. DESING OF REVESTMENT

When the velocity of the flow on the AMW exceeds the admissible velocity of the soil, a protective coating must be designed to control the risk of erosion and ensure the stability and durability of the structure.

The lining is the main element in the structural design of all hydraulic works or AMW, being the material exposed to the action of the current. Its objective is the protection of the natural terrain or soil structure, ensuring the stability of the hydraulic section and covering the surface exposed to the flow by means of a resistant and durable system throughout the useful life of the work.

In the planning, analysis and selection of lining alternatives, the geometry of the structure, support soils, erosion in the channel and design hydraulic solicitations must be taken into account.

Revetment dimensioned is a matter addressed by various researchers around the world. In particular, the guidelines of the publication "Design of Revetments" (K. W. Pilarczyk, 2002) by the renowned specialist author on the subject, belonging to the Dutch Public Works Department (RWS), Hydraulic Engineering Division (Delft, Netherlands) stand out. Said author studied a wide range of materials and coating systems, modern and traditional, under the same test conditions and safety criteria, according to the failure mechanism. The researcher's results are summarized in an empirical theoretical expression that allows the sizing of coatings considering both resistant aspects (thickness, density, porosity, continuity, roughness and others) and requesting conditions (tightness, speed, turbulence and others).

2.1 Abrasion resistance

In the design of the lining, the level of abrasion on the exposed surface of the hydraulic structure must be considered, verifying an adequate selection of the material adopted according to the abrasive conditions of the structure and watercourse according to its supply basin.

In all alluvial runoff, of high speed and short duration, there is the transport of sediments (sand and gravel) that produce abrasive wear on the friction surface, of greater intensity depending on flow speed and duration. In larger channels (larger basin and flow), in different rainfall events, the relevant flows are maintained for a long time, producing greater abrasive wear.

In the design of AMW, materials that allow greater resistance to wear or abrasion damage must be considered. In cases of aggressive or saline soils, materials resistant to corrosion or chemical degradation should be selected.

The traditional revetment (gabion) used in AMW is very sensitive to abrasion, where the wire can be easily damaged by abrasion and corrosion, then losing its confinement in the filling stones. Concrete block systems, while they may suffer some surface wear from abrasion, removing minimal thickness and weight from the revetment, are less vulnerable to this risk of damage.

3. STUDY OF REVESTMET ALTERNATIVES

In the search to optimize the construction cost, construction time and general performance of Alluvial Mitigation Works (AMW), which are designed for different case studies, considering a wide range of requests, terrain conditions and work sizes, A technical and economic evaluation of coating alternatives was carried out according to reference costs, obtained from YPF NOC contractors and suppliers, contemplating different construction methodologies that apply available, local or industrialized materials.

One aspect considered was the frequent demand for channels or lateral defences with low to moderate stress, where traditional materials (mat) present resistances much higher than hydraulic stresses, which implies a high-cost work solution compared to necessity.

The revetment evaluated were the following systems and their component materials:

1) GeAMWt / Geomembrane / Geotextile
2) Cement Blanket
3) Geobags
4) Rip rap
5) Precast concrete blocks
6) Geocell panels with concrete
7) Gabions
8) Block mats connected to geotextile lying
9) Cabled block mat
10) Reinforced concrete structures

Geosynthetic-based systems such as HPTRM type geomats, HDPE geomembrane, stabilized woven geotextile, geobags or cement blankets, of imported origin, are considered to be of high cost and limited application, being vulnerable to damage by abrasion, impact (footsteps, blows, etc.) or thermal action (torch, fire, etc).

The use of rockfill in YPF NOC areas has the disadvantage of not having a large size of stone (alluvial deposits), which limits its application to cases of low solicitation. On the other hand, round stone rockfills require laid slopes (1H:3V) with greater space and volume of work.

Geocell panels filled with concrete are a solution that is widely applied at YPF NOC for highly stressed channels (jumps, ramps, etc.). Its disadvantages are limited flexibility in free edges (protection at the foot) and difficulty of provision because it is an imported material (HDPE or Neoloy panels).

The traditional system applied at YPF NOC are mats and gabions, being the most widely used and experienced material in works. However, experience has shown that it is a material of limited application due to its low resistance to abrasion (wire damage) and moderate flexibility. The biggest disadvantage is its constructive complexity and quality compliance in terms of size and confinement of the stone, requiring high specialized labor and strict quality control.

The blanket of concrete blocks, adhered to a stabilized woven geotextile and provided with loops for adherence to the poured concrete, is a solution used by YPF NOC in AMW for the Protection of Pipeline Crossings over large channels, being a suitable material due to its high flexibility and resistance to abrasion. As a disadvantage, its high cost and moderate constructive complexity stand out.

The variant of this last system, where steel cables or synthetic ropes are used to link the concrete blocks, forming blankets of blocks, is a technology not available in the country at the moment.

H°A° structures are applicable in channels with high solicitation (jumps, ramps, etc.). Being a rigid structure, it requires flexible joints, drainage systems and high-quality control.

Lastly, the system of loose pre-cast blocks stands out, mainly for channels or lateral defences with low to moderate stress, being an industrially manufactured and simple-to-place material. The line of HR blocks (rough hexagonal) allows a system of low cost, low maintenance and high resistance to abrasion. Another advantage of the system is related to its possible disassembly and reconstruction, using the same material. Fundamental quality in the context of oil and gas facilities, where the dynamics of the activity causes permanent changes, works and interferences.

4. SELECTION AND DESIGN BLOCKS

Initially, the solution of geocell panels filled with concrete was implemented in situ, as a semi-flexible system with high resistance to abrasion, which exceeds the performance of traditional mats. In this application, the geocells are used as a mould or permanent formwork that allows confining the fresh concrete that later hardens, forming a blanket of blocks, interlocked and linked by a synthetic sheet (HDPE or Neoloy).

Searching for a precast concrete cladding option, the cost of provision and placement of precast elements was analyzed, using other similar systems as a reference (paving stones, tiles, etc.). In the first place, the HL60 block (hexagonal liso) was proposed, being a smooth hexagonal block 60mm thick and 250x290mm in size, as an element similar to the block formed in the geocell and at the same time similar to other precast elements such as paving stones for road use (60x100x200mm).

The use of HL60 block was adequate in channel projects with a low bottom slope (0.20 to 0.40%). Then, in channels with a steeper slope (0.50 to 1.50%), very frequent in YPF NOC lands, it was observed that their low roughness (n=0.020) caused an increase in flow velocity that originated a significant increase in necessary thickness and cost.

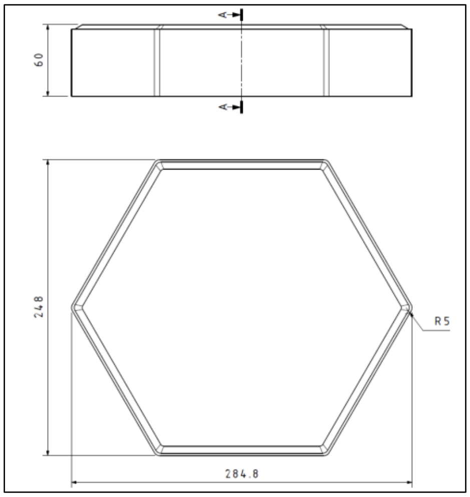

FIGURE 1: HL60 BLOCK DETAIL

In these first experiences of application of the HL system, the need to increase the Manning roughness or resistance to flow was visualized, to control the speed and reduce the cost of work.

After the first HL model, a new open and rough block was designed, provided with large holes that give it greater resistance to flow and less volume of concrete, obtaining advantages both in cost and in hydraulic performance. Different designs and sizes of commercial blocks from the United States and Europe were analyzed, where there are extensive developments of these precast systems.

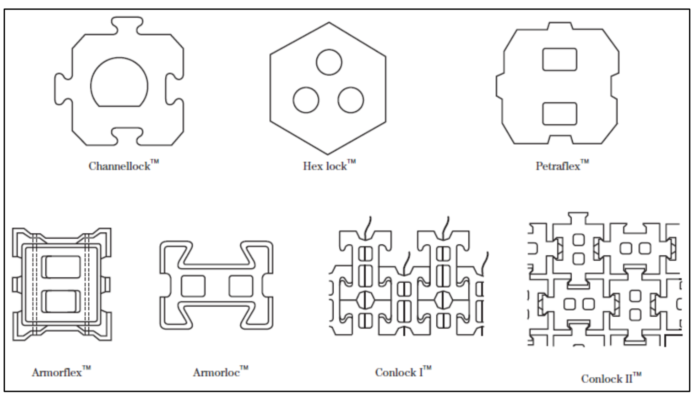

FIGURE 2: COMMERCIAL BLOCKS IN US

In the design of HR blocks (hexagonal rugoso), 2 geometries and 4 thicknesses were defined, according to the range of greatest application (60-80-100-120mm) and feasibility of manufacturing in automated vibro compaction machines. The 20mm increase between the HR block models means a variation of 20 to 33% of cost, which allows adjusting the thickness of the block and the cost of work according to the requests of each case study.

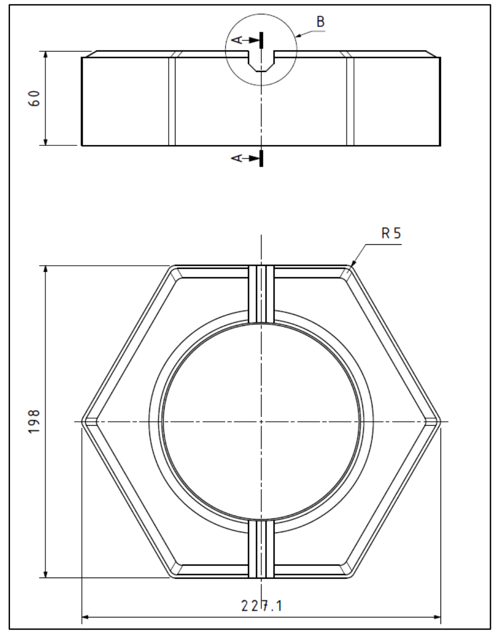

FIGURE 3: HR60 BLOCK DETAIL

In the study of sizes and geometries of HL and HR blocks, the technical support provided to YPF by the company CIMALCO, which has a precast plant in the city of Neuquén, equipped with an automated block making machine, stands out.

In the designs of the HR blocks, an open surface of 35% was proposed, achieving large holes that generate greater surface discontinuity and resistance to flow. In the same sense, the reduction of the volume of concrete and weight of the piece has a direct relationship with its cost of manufacture, transport and placement.

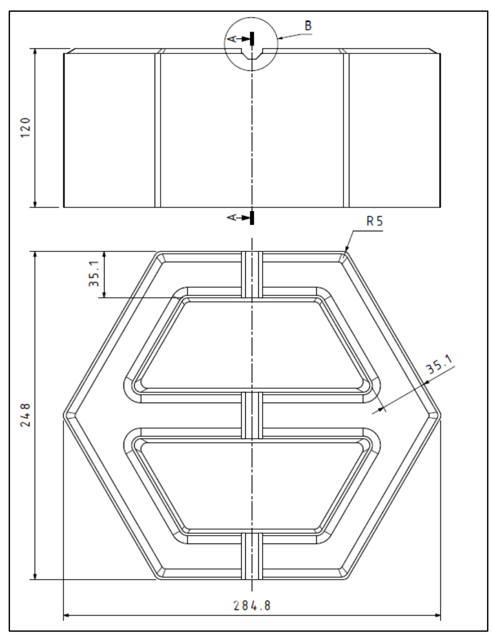

FIGURE 4: HR120 BLOCK DETAIL

5. MANUFACTURE OF BLOCKS

The manufacture of the HL and HR blocks is carried out in a precast industrial plant located 150km from the main works in progress. Each element is moulded by an automated block making machine equipped with a high-energy vibro-compaction system that allows high compaction of the fresh mix. The concrete is dosed for a dry mix with a high cement content, obtaining a quality similar to manufactured concrete H25 of 25 MPa of characteristic resistance according to the IRAM 1666 standard.

FIGURE 5: BLOCK MAKING MACHINE

The water/cement ratio is not used in the dosage of the mixture, being a dry concrete with zero slump. The constituent materials are rolled coarse aggregate of 10mm maximum size, two types of sand with different fineness modulus, normal Portland cement (CPN40) and a multifunctional plasticizing additive for vibro-compacted concrete. The cement content used is 370 kg/m3. The aggregates are local and processed (sieving and washing) 25 km from the molding plant.

The newly moulded pieces are placed in steam curing chambers that accelerate the hardening of the concrete, obtaining a resistance of 60% with 12 hours of curing. Then the blocks are packed on pallets and transported to the workshop.

Said industrialized and automated system for the manufacture of precast blocks allows a significant reduction in the manufacturing cost and, at the same time, guarantees a high-quality control of the block, through strict supervision of the mix dosage (granulometry, humidity, cement content, etc.), moulding, compaction and moist curing.

Sclerometry tests were carried out on the hardened pieces, using a calibrated instrument with specimens according to standards. These tests sought to corroborate the homogeneity of the concrete throughout the manufacturing process. Core extractions were carried out on sampling pieces and compression tests were carried out according to IRAM 1546 standard.

With respect to abrasion, the IRAM 11656 standard uses, as control parameters in concrete pavers for interlocking pavements, the abrasion test. In it, the piece is subjected to wear through a flow of abrasive material. Carrying out the same test on piece HL60 is under study.

FIGURE 6: STEAM CURING CHAMBER

FIGURE 7: PALLET PACKING

It should be noted that the HL and HR blocks are made with the same dosage, materials and manufacturing method that the CIMALCO plant uses for concrete pavers, which comply with the IRAM 11656 standard. Therefore, it is assumed that the quality of both pieces It's similar. The level of quality required in the standard for concrete pavers for pavements far exceeds the level of quality required in hydraulic coating blocks, exposed to less aggressive conditions.

6. CONSTRUCTION METHODOLOGY

The construction methodology of the premolded block coating is summarized in the following sequence: preparation of the substrate, laying of non-woven geotextile, placement of blocks, finishing the surface and execution of the crown.

6.1 Substrate preparation

The support surface or substrate must be conditioned by removing an upper layer of natural soil (minimum 20cm), cleaning any roots or other plant remains. In the case of embankments or fill soil structures, the selected soil must comply with a compaction of 95% modified Proctor. Finally, profiling and leveling the surface will be carried out according to the project.

6.2 Laying of non-woven geotextile

A non-woven geotextile (300 gr/m2) will be placed on the ground to act as a filter and separation. The geotextile is laid over the channel or slope to be protected, anchoring it properly with metal stakes. An overlap of 0.20m will materialize between neighboring blankets.

6.3 Block placement

Once the geotextile has been placed, the premolded blocks are manually placed from the slab to the slope. The blocks are placed manually ensuring maximum contact between blocks. Empty spaces between blocks, as well as protrusions or depressions on the surface, should be avoided. At the edges of the coated area, a semi-block or block fraction required to obtain a straight perimeter will be used. Empty spaces (curves, transitions, etc.) must be filled with fresh concrete.

6.4 Surface finishing

The surface finish will be regular, without spaces between blocks, without projections or depressions. The supporting substrate will need to be corrected if a regular surface will not be achieved.

6.5 Execution of the crowning

At the crown of the slope covered by blocks, a pre-molded tile 0.50m wide, 1.0m long and 60mm thick will be placed, provided with a tooth or projection as a fastening element on the last row of blocks on the slope.

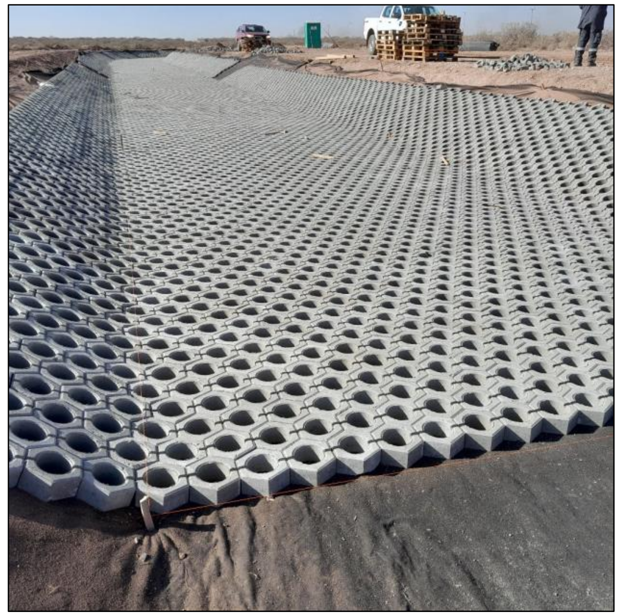

FIGURE 8: PLACEMENT OF HR80 BLOCKS

7. MANNING ROUGHNESS

In the publication "Stream Stability of Highway Structures" (FHWA, 2001) an expression is proposed to determine the resistance to flow in a channel, composed of a base value depending on the material and other values that have no influence in a regular stable channel. For a bottom material composed of gravels from 2 to 64mm, the publication proposes an n of 0.028 to 0.035.

Table 5.1. Base Values of Manning's n (n_b).

Channel or Floodplain Type	Median Size, Bed Material		Base n Value	
	Millimeters (mm)	Inches (in)	Benson and Dalrymple	Chow
Sand Channels	0.2	--	0.012	--
	.3	--	0.017	--
(Only for upper regime flow where grain roughness is predominant)	.4	--	0.020	--
	.5	--	0.022	--
	.6	--	0.023	--
	.8	--	0.025	--
	1.0	--	0.026	--
Stable Channels and Floodplains				
Concrete	--	--	0.012 - 0.018	0.011
Rock cut	--	--	--	0.025
Firm soil	--	--	0.025 - 0.032	0.020
Coarse sand	1 - 2	--	0.026 - 0.035	--
Fine gravel	--	--	--	0.024
Gravel	2 - 64	0.08 – 2.5	0.028 - 0.035	--
Coarse gravel	--	--	--	0.026
Cobble	64 - 256	2.5 – 10.1	0.030 - 0.050	--
Boulder	> 256	> 10.1	0.040 - 0.070	--

TABLE 1: BASE VALUES OF MANNING'S N COEFFICIENT (Stream Stability of Highway Structures, FHWA 2001, US)

Regarding concrete block revetment, there are tests from different organisms. In the case of the FWHA, different open and rough blocks were studied, recording roughness values of 0.030 to 0.050 depending on the type of block and flow conditions (source: "Hydraulic Stability of Articulated Concrete Block Revetment Systems During Overtopping Flow" (Federal Highway Administration, 1989).

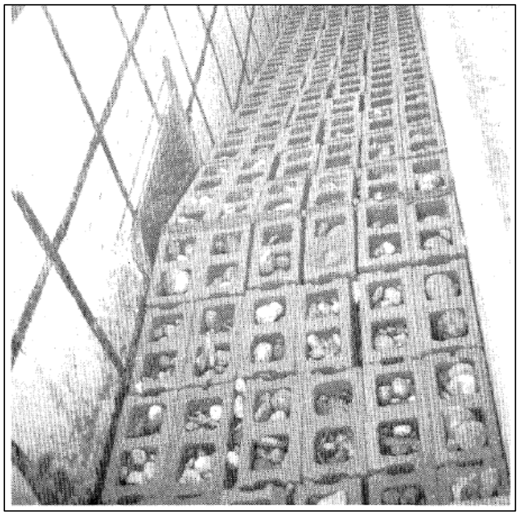

FIGURE 9: FHWA TESTED CONSTRUCTION BLOCKS

In the publication of the Instituto Nacional del Agua (INA) called "Study of the physical model of the behaviour of different types of bank protections against the action of currents" a comparative study of three types of bank protections against the action of the currents, in a mobile depth physical model built for this purpose. Based on the determination of the resistance coefficients evaluated with the slope of the power line for the systems tested, the study recommends the following average values:

- Blocks mat adhered to geotextile: n = 0.024
- Gabion: n = 0.035
- Loose precast blocks: n = 0.020

In October 2022, the Hydraulics Laboratory of the Faculty of Engineering of the University of Stellenbosch, South Africa, published a study called "Hydraulic Model Study: Bosun Buffalo Erosion Protection Blocks" commissioned by the Bosun Precast company to study the performance of the block. "Buffalo", being an open block of 200x400mm and 100mm thick provided with 6 holes of 40mm diameter. Said block was tested in a physical model for different flow conditions, obtaining Manning's n values of 0.024 to 0.032.

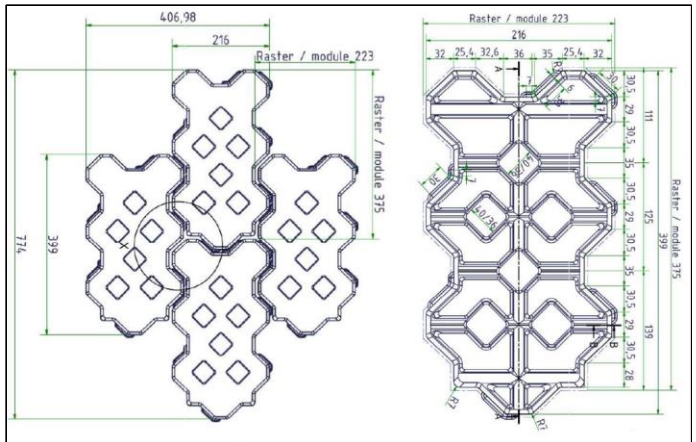

Figure 2-3: Prototype dimensions for the Bosun block module

FIGURE 10: BUFFALO BLOCK TESTED IN SOUTH AFRICA

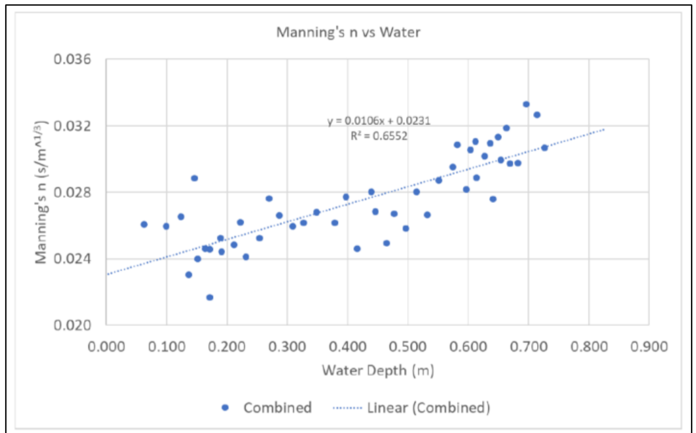

Figure 4.1-1: Observed Manning n values from the model study data converted to prototype data

FIGURE 11: N MANNING VALUES OBTAINED IN BUFFALO BLOCK TESTED

Based on bibliographical references and laboratory tests of commercial blocks, it was proposed to adopt, for the hydraulic design of structures with HR blocks, a Manning roughness of 0.030 for subcritical flows and depths of 0.30 to 0.80m. In case of supercritical flow and depths less than 0.30m, a slight increase in roughness was considered, adopting a value of 0.035.

8. CURRENT STABILITY

The stability verification of loose precast block-type coatings was carried out according to the guidelines of the publication "Desig of Revetment" (K. W. Pilarczyk, 2002) which proposes the following expression and calculation parameters:

$$\Delta D = 0.035\ \frac{\Phi}{\Psi}\ \frac{K_T\ K_h}{K_s}\ \frac{{U_{cr}}^2}{2g} \qquad (1)$$

Where:

Δ: relative density
D: average revetment thickness (m)
Φ: stability parameter
Ψ: Shield parameter
K_T: turbulence factor

K_h: depth factor

K_s: slope factor

U_{cr}: critical velocity (mean flow)

g: acceleration of gravity ($g=9.81 m/s^2$)

Average thickness and relative density (D y Δ):

The values of average thickness and relative density are defined according to the specific system:

For rocks: $D = D_n = (M_{50}/\rho_s)^{1/3}$ (nominal diameter) y $\Delta = (\rho_s - \rho_w) / \rho_w$

For blocks: D = thickness of the block and $\Delta = (\rho_s - \rho_w) / \rho_w$

Fot mats: D = d = average thickness of the mat and $\Delta = (1-n)(\rho_s - \rho_w) / \rho_w$, where n = porosity of the fill.

Where:

ρ_s = density of the material (kg/m3).

ρ_w = density of water (kg/m3).

In the case of rockfill or loose blocks, the calculation density is equal to the density of the material, not including the porosity of the set. In continuous systems (block blankets, mats, etc.) the relative density must include the porosity of the whole.

Adopting a concrete density of 2300 kg/m3, a relative density of 1.30 is obtained for the loose precast blocks.

Stability parameter Φ:

The stability parameter Φ depends on the application, some guide values are indicated:

- Rockfill and loose blocks: Continuous layer: 1.0 - Edges or transitions: 1.5
- Blanket of blocks, mats and geobags: Continuous layer: 0.5 to 0.75 - Edges or transitions: 0.75 to 1.0

For the stability parameter Φ, a value of 1.00 is adopted for the loose blocks, considering a continuity of the lining.

Shields parameter Ψ:

The critical parameter of Shields Ψ depends on the type of material, the following values are indicated:

- Rip rap and small geobags Ψ ≈ 0.035
- Loose blocks and geobags Ψ ≈ 0.05
- Block mat Ψ ≈ 0.07
- Gabion Ψ ≈ 0.07

For the value of the parameter Ψ a value of 0.05 is adopted for loose blocks.

Turbulence factor K_T:

The degree of turbulence is considered by the following factor:

- Normal turbulence (straight lines) KT ≈ 1.0
- Increased turbulence (curves) KT ≈ 1.5
- Increased turbulence. (neg. under bowl) KT ≈ 1.5
- High turbulence (hydraulic jump) KT ≈ 2.0
- High turbulence (abrupt changes) KT ≈ 2.0
- High turbulence (jet flow) KT ≈ 3.0 to 4.0

The K_T turbulence factor is assumed equal to 1.25 in the case of a channel in a uniform regime in slow flow (subcritical), assuming a slight increase in turbulence in curves and changes in section. For fast flow channels (supercritical) it adopts a value of 1.50. For energy dissipating bowls, a value of 2.0 was adopted.

Depth parameter K_h:

For an undeveloped velocity profile, the expression is adopted:

$$K_h = \left(\frac{h}{ks}\right)^{-0.20} \quad (2)$$

Where:

h: depth (m)

k_s: Nikuradse equivalent roughness (m).

For the equivalent roughness value (k_s) in the case of smooth blocks (HL or CL type block), a value of 20mm (0.02m) was adopted, as a smooth and regular concrete surface. For rough blocks (type HR) a value equal to the thickness of the block or a maximum of 100mm is adopted.

Slope parameter K_s:

The slope factor K_s depends on whether the stability of the lining is analyzed on the bottom or on the slope. In each case, the bibliography proposes the following expressions and parameters:

$$K_s = \sqrt{1 - (\frac{\sin\alpha}{\sin\theta})^2} = \cos\alpha \sqrt{1 - (\frac{tan\alpha}{tan\theta})^2} \quad (3)$$

$$K_s = \cos\alpha_b \quad (4)$$

Where:

θ = angle of internal friction of the lining material

α = cross section slope (°)

α_b = bottom slope in the direction of flow (°).

The following values of θ can be assumed according to the author: 40° for angular riprap, 30° to 40° for geosandbags and 90° for contact-linked block systems (geocells).

For the system of blocks adhered to a geotextile, without contact between blocks, θ is 15° to 20°.

In the case of loose blocks, a friction angle between blocks of 45° was adopted.

The calculation parameters adopted arise from the average values recommended by the author of the method in his latest publications. Some of these parameters have a high sensitivity in the result of the allowable speed. In general, a conservative criterion was maintained in the application of the method, due to the lack of specific studies that support other calculation values.

The Pilaczyk method allows a dimensioning of the block thickness for the bottom or slope of a lined section. In the case of channels, a constant thickness is used constructively throughout the section. Usually, the channels designed in the AMW of YPF NOC have a high screed width in relation to the tie rod (B/h > 1). In addition, it is known that the velocity field on a slope registers high velocities only in its final section (foot), then the velocity decreases due to the reduction of depth and greater resistance to flow. It can be assumed that the section with the greatest demand on the current on a slope is half of its development.

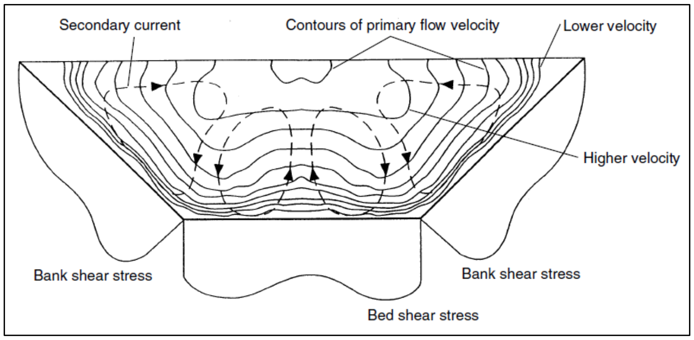

FIGURE 12: DISTRIBUTION OF VELOCITY AND SHEAR STRESS IN A TRAPEZOIDAL SECTION

For the calculation of the average thickness of the section, a weighting of the bottom and slope thicknesses is carried out according to the relationship between the bottom perimeter and half of the perimeter in slopes. In channels with a high bottom width, in relation to the depth, the average thickness value is close to the bottom thickness value. The simplifications assumed in the Pilaczyk method allow a simple cladding dimensioning tool in structures of different geometries.

The following figure shows the admissible speed for the different HR and HL blocks considering a 0.50m tie rod and a 5m screed width.

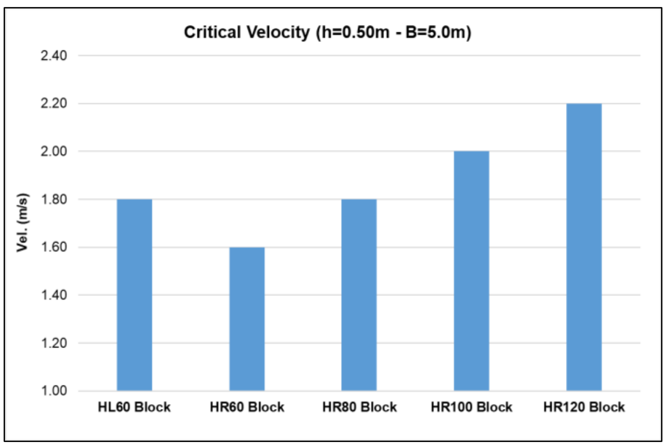

FIGURE 13: CRITICAL VELOCITY VALUES

It should be noted that the Pilaczyk expression is a highly secure calculation tool for this type of system, which allows a simple sizing of the coating considering the main factors that influence its stability to current. In different published tests on concrete blocks subjected to flow in a full-scale or reduced-scale channel, failure speeds of 3 to 6m/s have been obtained, much higher than those estimated by the Pilaczyk methodology. These experimental results together with other stability verification methodologies allow us to affirm that the permissible speeds used in the HR and HL blocks maintain a safety margin at the beginning of movement and system failure.

Another aspect to consider is the high recurrence (100 years) required by the Application Authority to determine the design flow rates, being short duration events, which implies a low explosion and less risk of lining failure.

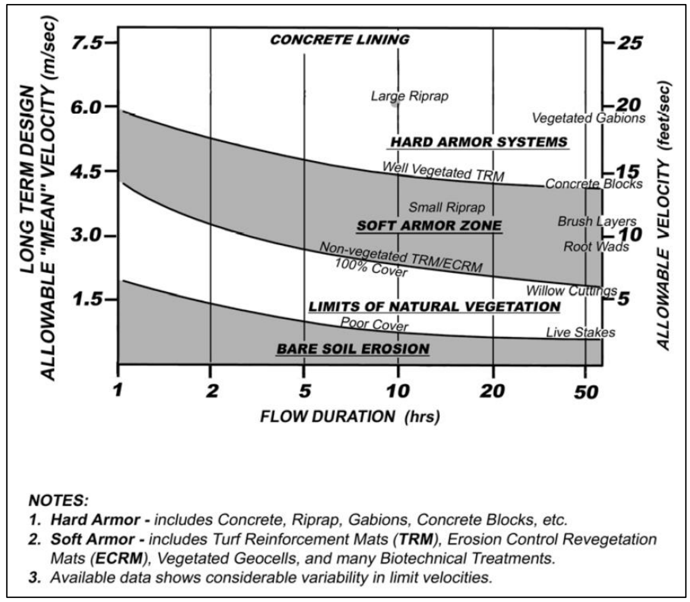

FIGURE 14: ALLOWABLE SPEED VALUES ("STABILITY THRESHOLDS AND PERFORMANCE STANDARDS FOR FLEXIBLE LINING MATERIALS IN CHANNEL AND SLOPE RESTORATION APPLICATIONS", FISCHENICH ET AL, 2012)

9. ECONOMIC EVALUATION OF ALTERNATIVES

In the Engineering and Construction Management of YPF Unconventional (a sector that Vaca Muerta exploits) a specific contract was made for the construction of AMW, defining a wide itemization of tasks, materials and coating systems, applied in different works. These contract prices allow us to make an economic comparison of coating alternatives, being quoted by the same contractor under the same work conditions.

The images below show the relative prices, based on the most economical system (Block HR60), of the different system alternatives analysed, both for low and moderate hydraulic solicitation. In the case of the rip rap, being the only item not considered in the contract, a price per cubic meter was adopted, which represents 60% of the price of the mat. It should be noted that, in both project scenarios, the HR blocks have a clear economic advantage over other alternatives.

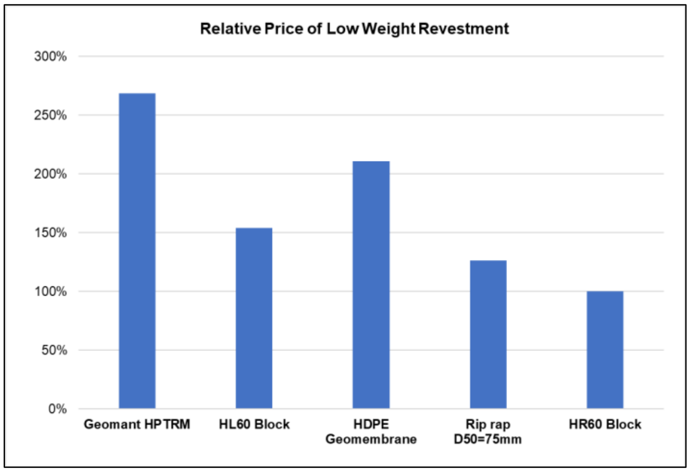

FIGURE 15: RELATIVE PRICE OF LOW WEIGHT REVESTMENT

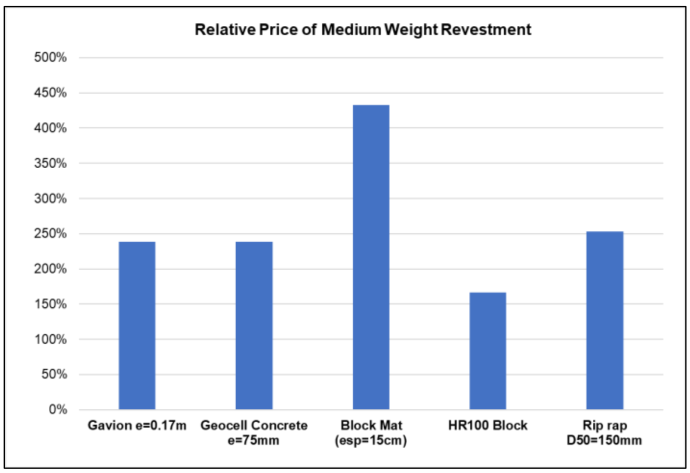

FIGURE 16: RELATIVE PRICE OF MEDIUM WEIGHT REVESTMENT

10. WORK CASE: AMW PTC LACH

To protect the PTC LACH Plant (Oil Treatment Plant - La Amarga Chica) from the natural runoff of the NE sector, a trapezoidal Channel was designed with a bottom width of 5.0m, height of 0.80m and slopes 1V:2H for a flow of 4.24m^3/s associated with a rain of 100 years of recurrence.

The channel has a total development of 740m, divided into sections of different slope and coating. It starts with a 140m stretch with HR60 Block and a 0.40% slope, then continues with a 265m stretch with HR80 Block and a 0.77% slope. In its final section of 130m and a slope of 1.22%, HR80 Block is used again. The HR60 Block revetment was designed with a speed of 1.54m/s and a depth of 0.46m. In the sections with HR80 Block it was designed with a speed of 1.78m/s and a depth of 0.41m.

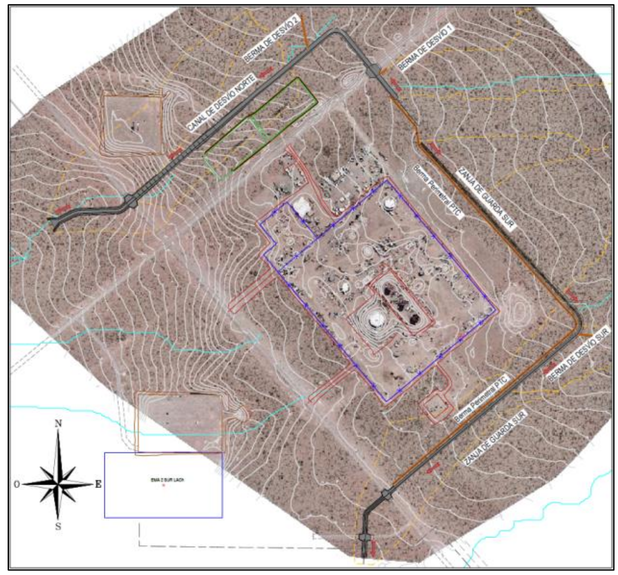

FIGURE 17: LAYOUT OF AMW PTC LACH

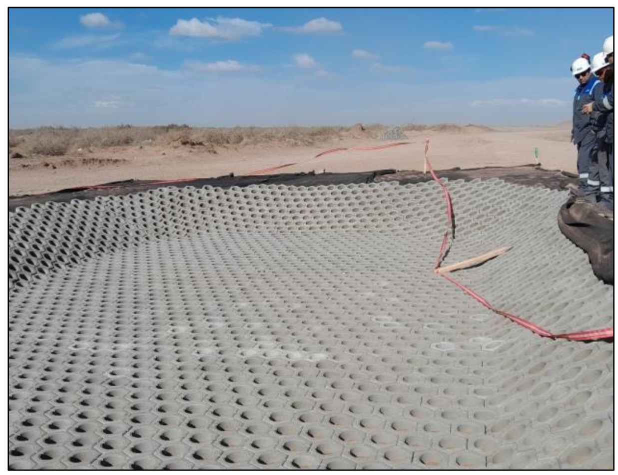

FIGURE 18: BEGINNING OF NORTH CHANNEL IN HR60 BLOCK

FIGURE 19: NORTH CHANNEL SECTION IN HR80 BLOCK

In the East and SE sector of the PTC LACH, a trapezoidal section channel of 2.0m botton width, 0.60m height and 1V:2H slopes for 0.77m3/s (TR10) was designed, verifying a flow of 1.72m^3/s (TR100). Said channel has a total development of 970m, of which some 520m are lined in HR60 Block with a slope of 0.78%. The lining was designed (TR10) with a speed of 1.10m/s and a depth of 0.28m.

FIGURE 20: SOUTH CHANNEL SECTION IN HR60 BLOCK

FIGURE 21: HR60 BLOCK AFTER ITS OPERATION

As can be seen in the previous image, after a rain and a certain flow carried by the Channel Sur, the stabilization of the soil was observed, where the blocks retain sediment in their holes and joints, which allows rapid consolidation of the system.

11. WORK CASE: AMW BAT9 BS

To protect Bandurria Sur Battery 9 Plant (BAT9 BS) from runoff from the South sector, a trapezoidal section Channel was designed with of 1.50m botton width, a height of 0.70m and slopes 1V:2H for a flow rate of 1.20m^3/s (TR10), verifying a flow of 2.60m^3/s (TR100).

The channel has a total development of 270m, divided into sections of different slope and revetment. It begins in a 240m stretch with HR60 Block and a 1.20% slope. The revetment was designed with a speed of 1.50m/s and a depth of 0.37m.

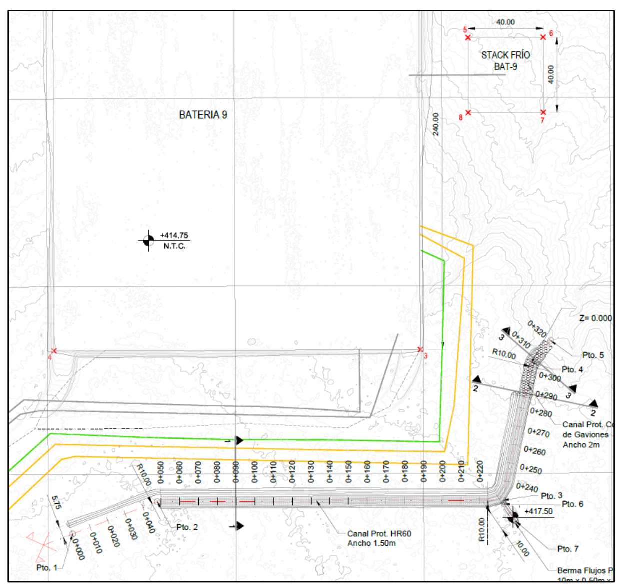

FIGURE 22: LAYOUT OF AMW BAT9 BS

FIGURE 23: CHANNEL IN HR60 BLOCK

FIGURE 24: DETAIL OF JOINTS IN CURVED HR60 BLOCK

12. DETAILS AND FINISHES

For the AMW projects, using the new HR Block revetment, it was necessary to design some details and finishes typical of a precast system. With the work experience, other construction details to consider were added, resolving singularities in the geometry or continuity of the system.

After the first work experiences, it is concluded that the system does not present particular constructive complexities, on the contrary, it simplifies aspects such as: transport and collection of material, labour for placement, patching of the support substrate, replacement of damaged parts, adjustments and corrections, etc.

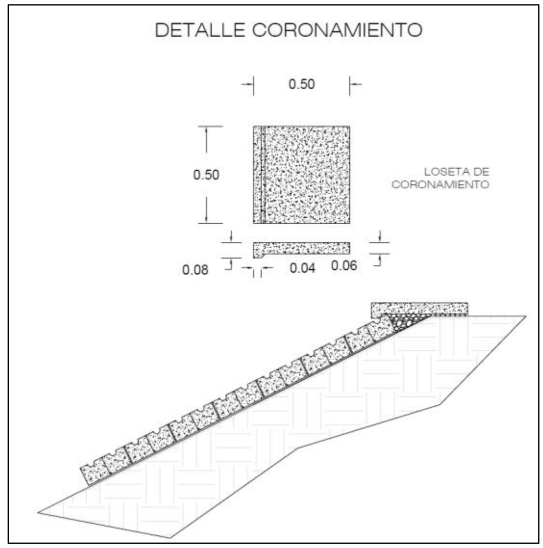

FIGURE 25: DETAILS OF CHANNEL TOP

FIGURE 26: LOSETA DE CORONAMIENTO

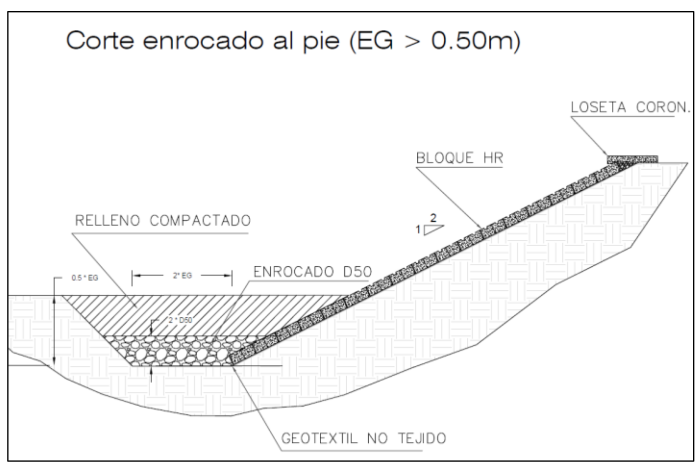

FIGURE 27: DETAILS OF TOE PROTECTION WITH RIP RAP

FIGURE 28: PROTECCION AL PIE CON ENROCADO

13. RESULTS AND DISCUSSION

The HR block system, as a revetment applied in numerous works in progress and others in project, located in YPF NOC areas, presents clear economic, constructive, and operational advantages over other systems available in the region. The main advantages of the system are the following:

1) Constructive ease
2) High execution performance
3) High quality of finish
4) Less supervision requirement
5) Detachable and reusable
6) Variable roughness (HL or HR)
7) Low cost of provision and placement
8) Low freight cost for longer distance works
9) Low maintenance
10) High abrasion resistance

With respect to placement, a high yield of 200m2/day was recorded (HR80 Block) for a standard crew of 5 operators. In this same sense, the simplicity of the task, low-skilled labor and low need for supervision or quality control stand out.

On the other hand, the following disadvantages to consider in its application were identified:

a) Moderate resistance to current due to limitation in thickness and block size
b) Moderate adaptation to complex geometries
c) Limited industrial production capacity
d) High cost of the metallic mold of each block model
e) Moderate flexibility
f) Not continuous, requires treatment of free edges

The monitoring of the construction process and its functional stage will allow a greater knowledge of the engineering of the material, identifying possible adjustments and constructive details or system improvements, as well as its limitations.

In the future, it is intended to carry out a study in 3D hydraulic modelling (CFD) in order to determine aspects of stability and resistance to flow (roughness), under the system design conditions.

The numerical simulation will allow a more precise knowledge of the operation of the system, supporting the experimental phase in full development. In the scope of the study, the current geometries (HR) will be analysed as well as new models under study. It is intended to analyse a block model called HAR (high roughness hexagonal) of similar size to HR120, modifying its geometry to achieve greater resistance to flow (greater roughness).

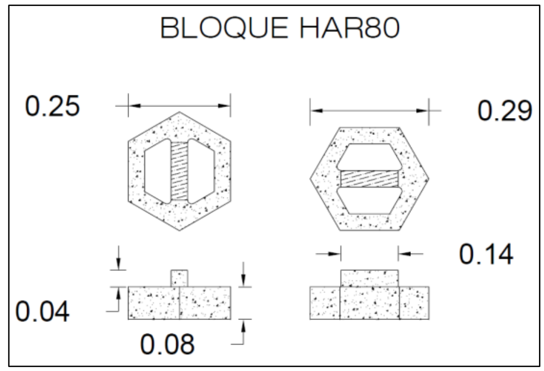

FIGURE 29: DETAILS OF HAR80 BLOCK (IN STUDY)

In the same sense, it is intended to analyse the behaviour of a model called MR (macro rough) that allows extending the use of precast blocks in channels with a steeper slope (2 to 5%) and replace the HR120 models in channels of moderate slope (1 to 2%).

With the results of these studies, new studies and tools will be evaluated to improve the representation of the hydraulic behaviour and failure mechanisms of the system, as well as possible adjustments in the geometry of new blocks for future developments.

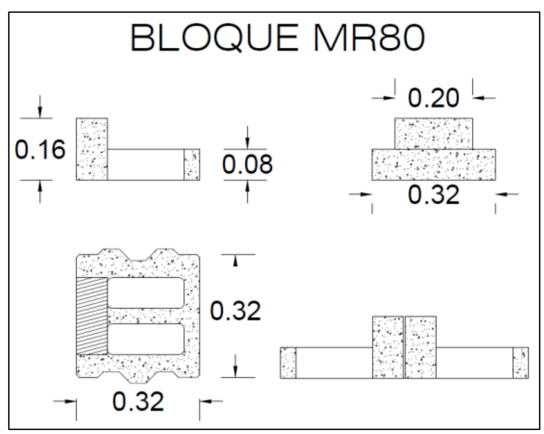

FIGURE 30: DETAILS OF MR80 BLOCK (IN STUDY)

14. CONCLUSION

The development of a system of precast blocks, adjusted to the needs of YPF NOC, is presented as an innovative engineering tool both to improve performance and to reduce costs of alluvial mitigation works in execution and design.

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